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STATIONARY METEOR-RADIANTS.

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Meteoric phenomena offer a field for investigation rich in the possibility of important contributions to the solution of the problem of cosmogony. The orbits of meteors seem, like those of comets, to be in the main very eccentric. No theory of the evolution of a world system can be complete without accounting for these eccentric orbits as well as the more or less approximately circular orbits of the great planets and asteroids. The object of this note is to point out one of the most striking of meteoric phenomena and to call the attention of our non-professional astronomers to the importance of this field of investigation, which is easily accessible to them. Observations of the flight of meteors have hitherto generally been made with no more apparatus than a short wand and a sphere of wood, upon which the star constellations have been mapped. More accurate observations of the direction of flight and the velocity of the meteor require two cameras of short focus and wide angle with especially arranged shutters.

Mr. W. F. DENNING, of Bristol, England, began to observe the flights of meteors at the time of the *Leonid* shower in 1866. Since that time, he has observed many thousands of meteor flights and our knowledge of the observed phenomena of meteoric display has been greatly increased by his contributions. Mr. DENNING's method of observation is exceedingly simple. He takes up a position on a moonless night in his garden with a short wand in his hand and a sphere upon which the constellations visible on that evening are plotted. When a meteor appears, he raises the wand as quickly as possible and holds it so that its projection on the sky shall coincide as nearly as possible with the path of the meteor.

This enables him to note quite accurately the location of the path of the meteor with reference to the neighboring stars. This path is then plotted on the sphere and the time noted. On a good night, Mr. DENNING observes on the average about eleven such trails per hour. Upon comparing these trails, it is observed that several of them would intersect in the same point if they were extended in the arc of a great circle some distance back of the point where the meteor became luminous, and therefore visible. These several paths would all seem to diverge from the same point. This indicates that these meteors were traveling in parallel paths at the time of their collision with the Earth. An analogous phenomenon is observed when seemingly divergent bars of sunlight are seen piercing a cloud. The point on the celestial sphere from which several meteor paths seem to diverge is called a "meteor-radiant." Its right ascension and declination are noted and entered in a catalogue of meteor-radiants, of which Mr. DENNING has published two, one in the *Monthly Notices* and the other in the *Memoirs of the Royal Astronomical Society of Great Britain.*

It is to be noted that the position of the radiant point depends solely upon the *direction* of the motion of the meteor *relative to the Earth.* This relative motion of the meteor is the resultant of the composition of the velocity of the Earth with that of the meteor. If either of these components changes its direction, the direction of the resultant changes. Now, suppose there were a great swarm of meteoric particles moving in parallel lines through the solar system so as to cross the Earth's orbit at all points, then we should encounter some of the meteors of this swarm every night in the year. If these meteors were observed at different intervals throughout the year and their radiant points determined, we should of course find the radiant point shifting from night to night, the shift being due to the changing direction of the Earth's motion as it describes its orbit. An example of this phenomenon is found in the *Perseid* family. Meteors of this family are seen as early as the 19th of July and as late as the 25th of August, and the shifting of the radiant amounts to about forty degrees. Mr. DENNING's ability to observe distinguishing characteristics so as to be able to classify meteors according

to families has been questioned, but his claim that long experience and careful observation have enabled him to distinguish differences of color, velocity of flight, length of path, or peculiarities in the illumination, which escape inexperienced observers and by means of which he identifies a meteor as belonging to any particular family, must be admitted.

The announcement of his discovery of *stationary radiant* points created a good deal of wonder and not a little discussion among those interested in meteoric phenomena from the theoretical point of view. Mr. DENNING asserts that there are certain radiant points stationary in the sky from which meteors presenting common "family" characteristics appear to diverge throughout intervals of weeks and even months. The incredulity of theoretical astronomers can be realized when one tries to picture to himself the complicated system of orbits in which the various meteoric particles of such a family of meteors would have to move. As the Earth moves about in its orbit, changing the direction of its motion by about one degree a day, the direction and magnitude of the velocity of the meteoric particles would have to vary so that the resultant would have a constant direction. Computation of orbits of meteoric particles coming from the same radiant at different dates have been made.[1] Some of the orbits were found to be direct and some retrograde, and the greatest diversity appeared in the case of the other elements, as might have been expected.

Mr. DENNING'S catalogue records the positions of a large number of stationary radiants. Among the most important are (*Monthly Notices*, Vol. 45, p. 101) :—

	α	δ	Apparent Duration.	Shower.
I	30°.0	36°.0	July 16–Nov. 14	β *Triangulids*
II	46 .0	45 .6	July 6–Nov. 30	α-β *Perseids*
III	61 .0	47 .7	July 25–Nov. 27	μ *Perseids*
IV	61 .8	36 .8	Aug. 2–Dec. 31	ϵ *Perseids*
V	76 .2	32 .6	July 23–Dec. 27	ι *Aurigids*
VI	80 .2	22 .9	Aug. 24–Jan. 15	ζ *Taurids*

Mr. DENNING speaks as follows concerning the phenomenon (*Monthly Notices*, Vol. 45, p. 111) : "The first decided intimation of their presence is usually recognized when the

[1] BREDIKHINE: *Bul. de l'Acad. de St. Petersbourg*, V Serie, T. 12, p. 95, T. 13, p. 189. TISSERAND: *Comptes Rendus*, T. 109, p. 345.

radiants are near the Earth's apex. At such times they furnish very swift streak-leaving meteors. Later on, they lose the capacity to generate streaks, and ultimately are transferred into the slow train-bearing meteors whose radiants cluster in regions far removed from the Earth's direction of motion. Yet during the whole time of the display, and while the individual meteors are thus visibly affected by the change, progressing from night to night, in the position of their divergent points relatively to the Earth's apex, their radiants remain immovable; and the fact is conclusively proved, not by approximate accordances, but by absolute coincidence in these points as observed with great care and precision."

Two ingenious and suggestive explanations of the phenomenon of stationary radiation appeared in the *Monthly Notices of the Royal Astronomical Society,* Vol. 59, p. 140 and p. 179. Professor TURNER, of Oxford, endeavored to explain the growth of such a family of orbits by the perturbation of the Earth upon a family of meteoric particles moving at first in nearly identical orbits which intersect the Earth's orbit at some particular point. There are serious objections to this theory. One very general consideration that militates against *any* theory based upon the perturbative effect of the Earth upon a single family of meteors is appended in a supplementary note.

The other explanation which appeared in the article above referred to in the *Monthly Notices* is by Professor A. S. HERSCHEL. He calls attention to the fact that if a resultant velocity is produced by the composition of one very large and one comparatively small velocity, a change in the direction of the small velocity does not materially change the direction of the resultant. If the velocity of the meteors were several hundred miles per second, the phenomenon of stationary radiation could be accounted for on the assumption of a broad stream of meteors crossing the Sun's system in parallel straight lines. The changing direction of the Earth's velocity would alter the direction of the resultant so slightly that the radiant would be stationary within the error of observation. The velocity of meteors as they fall upon the Earth is not, however, anywhere near so great as three or four hundred miles per second. So far as observations go, the evidence seems to

point to an orbital velocity of the meteoric particles not very different from the parabolic velocity. Now comes the ingenious part of Mr. HERSCHEL'S theory. He supposes that at some time in the past history of the solar nebula, before the material forming the Earth had liquefied, the solar system encountered a storm of meteoric particles moving in parallel lines at a velocity of several hundred miles per second. These particles pierced the nebulous material that was moving in the orbit in which the Earth now travels and passed through it, suffering a greater or less retardation. This meteoric storm might have endured for months or for years, and the radiant points of all the meteors would have been nearly the same because of the high velocity of the oncoming meteor particles. We may say the particles would have a common radiant within the error of observation. Now, it is to be observed that the retardations of any meteoric particle by the nebulous mass is tangential, so that *the radiant point remains unchanged as the particle passes through.* Its velocity relative to the nebulous ball as it leaves is identical in *direction* with its relative velocity as it approaches, the magnitude only having been changed by the retardation. Now, such of these particles as escape from the nebulous ball with a velocity less than the parabolic velocity will return again at some future time (perturbations neglected) to the same point and with the same velocity. Such of these particles as encounter the Earth again at some future date will have a common radiant,—namely, the radiant of the original meteoric storm.

The suggestiveness of this theory is remarkable. It offers an explanation for the origin of comets as masses of matter that have in ages past collided with the solar nebula and lost so much of their velocity that they were unable to escape from the Sun's system. The remarkable gap in continuity between the nearly circular orbits of the great planets and the very eccentric and long-period orbits of the comets and meteors is accounted for; the lack of many short-period, highly eccentric orbits being due to the great probability of collision or disintegration at the frequent perihelion passages. Such a meteoric storm, occurring at a critical stage in the development of a planet might have produced a disruption resulting in the formation of the asteroid ring.

The importance of research to confirm or disprove Mr. DENNING's claim of the existence of stationary radiation, and the ease with which observations may be made, ought to recommend it to any one interested in the progress of astronomy. The vital connection which Mr. HERSCHEL's explanation of stationary radiation gives the question of its actuality with the problem of the development of a world system lends such investigations a dignity which is in no wise impaired by the simplicity and seeming crudeness of the means employed. The clear sky, uniform good weather during the summer-time, and transparency of the atmosphere render many points in the interior of California peculiarly adapted for investigations of this sort.

NOTE.—In the above note on "Stationary Meteor-Radiants" I have alluded to a general objection to any theory which offers to explain the rise of a system of orbits to which stationary radiation might be due through perturbation, by the Earth, of meteoric particles originally moving in the same elliptic orbit. I shall show by an application of TISSERAND's[1] criterion for the identity of two orbits that one of the orbits of such a family could not be produced from another by the perturbation of the Earth alone.

If any orbit has been produced from another by the perturbation of the Earth, the following relation must exist between the elements of the two orbits:—

$$(1)\ \frac{1}{a} + 2\sqrt{a\,(1-e^2)}\cos i = \frac{1}{a'} + 2\sqrt{a'\,(1-e'^2)}\cos i'$$

i and i' being the inclinations of the plane of the orbit of the disturbed body to the orbital plane of the disturbing body.

Mr. DENNING does not make accurate observations of the velocity, and it is therefore impossible actually to compute the various orbits belonging to a stationary radiant. The following statements previously quoted will however furnish sufficient data for the present purpose. He says (*Monthly Notices,* Vol. 45, p. 111): "The first decided intimation of their presence is usually recognized when the radiants are near the Earth's apex. At such times, they furnish very swift

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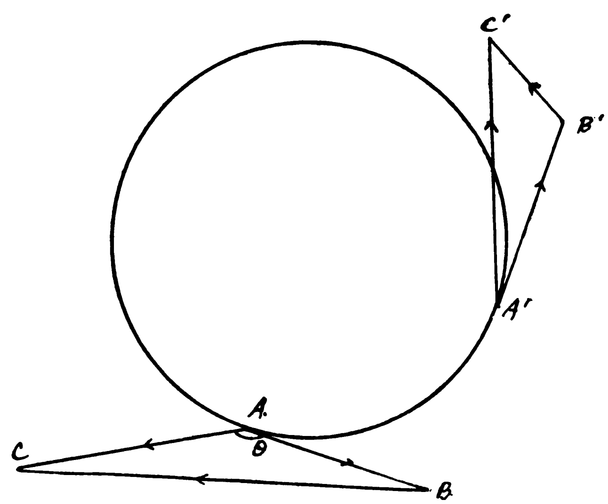
[1] TISSERAND: *Mech. Cel.*, Vol. IV, p. 204.

streak-leaving meteors." In his catalogue of 1890 (*Monthly Notices,* Vol. 50, pp. 418 ff.) he uses the following adjectives to characterize meteors as regards velocity: "very slow," "slow," "rather slow," "swift," "rather swift," "very swift."

The following considerations lead to the conclusion that the orbit of the meteoric particle which meets the Earth when the radiant is near the apex is retrograde. Mr. DENNING'S notion of "very swift" is obtained by comparison with other meteors. It is definitely known that the *Leonid* meteors, for example, are traveling with an orbital velocity appropriate to an orbit of thirty-three years period. They meet the Earth when the radiant point is near the apex, and the velocity relative to the Earth must therefore be more than twice the orbital velocity of the Earth. (Let us leave out of account the acceleration due to the Earth's attraction.) It is safe to say that a meteoric velocity would not be described as "very swift" by Mr. DENNING unless its velocity relative to the Earth, exclusive of that due to the Earth's attraction, were at least twice the orbital velocity of the Earth. Mr. DENNING'S catalogue also shows that many of the stationary radiants en-



dure for more than three months. In the figure let the circle represent the Earth's orbit, the vectors AB and AC represent the velocity of the Earth and meteoric particle respectively.

The vector BC represents the motion of the particle relative to the Earth. The vectors AC and BC are not necessarily in the plane of the paper. The angle ABC is the angular distance of the radiant point from the apex of the Earth's way. This is less than 90°, if the longitude of the radiant point is equal to that of the apex.

$$\overline{BC}^2 = \overline{AB}^2 + \overline{AC}^2 - 2\overline{AB}.\overline{AC}\cos\theta$$

If $BC = 2AB$

$$3\overline{AB}^2 = \overline{AC}^2 - 2\overline{AB}.\overline{AC}\cos\theta$$

Either $\overline{AC} \gtreqless \sqrt{3}\,\overline{AB}$

or, $\cos\theta < O$.

But $\sqrt{3}\,\overline{AB} >$ parabolic velocity $= \sqrt{2}\,\overline{AB}$

Such a velocity could not have been produced by a previous perturbation of an elliptic orbit, for a particle leaving on a hyperbolic orbit would not return. The other alternative remains, and the orbit is retrograde, the angle θ being greater than 90°. The orbits of these particles which meet the Earth when the longitude of the apex is equal to the longitude of the radiant are, then, retrograde.

When the longitude of the apex is 90° greater than the longitude of the radiant the angular distance between the apex and the radiant ($= A'B'C'$) $> 90°$. The orbit is necessarily direct (since $B'A'C' < 90°$) and the projection of $A'C'$ upon $A'B'$ is therefore greater than $A'B'$.

The elements a and r of a meteor's orbit are expressed as follows (TISSERAND'S *Mech. Cel.,* Vol. I, p. 101 and p. 97) :—

$$\sqrt{a\,(1 - e^2)} = \sqrt{p} = \frac{r^2\,dw}{k} = \frac{r\,V \sin\sigma}{V_e}$$

$$\frac{1}{a} = \frac{2}{r} - \frac{V^2}{k^2} = 2 - \frac{V^2}{V_e^2}$$

Here r represents the radius vector of the Earth, taken equal to unity, V the velocity of the meteor, V_e the velocity of the Earth, and σ the angle between the radius vector and the tangent to the meteor's orbit; k is the Gaussian constant, equal

to the velocity of the Earth, in the units here employed. Substituting these values in equation (1), placing

$$D = \sin\sigma \cos i$$
$$D' = \sin\sigma' \cos i'$$

and solving for V, we have

$$V = V_e D \pm \sqrt{V_e^2 D^2 + V'^2 - 2V_e V'D'}$$

D is negative and D′ positive, since $i > 90°$ and $i' < 90°$, the first orbit being retrograde and the second direct; also $\sigma < 180°$. V is necessarily positive, but there is no positive solution of the equation unless

$$V'^2 - 2V_e V'D' > O$$
$$V' > \sqrt{2V_e V'D'}$$

Now V′D′ is the projection of V′ on A′B′ and

$$V'D' \gtreqless V_e \text{ according as}$$
$$A'B'C' \gtreqless 90°$$

It follows that TISSERAND's criterion is not satisfied by the two orbits, unless

$$V' \gtreqless \sqrt{2}V_e$$

But $\sqrt{2}V$ is the parabolic velocity, and, as has already been noted, such an orbit could not have been produced by a previous perturbation.

This test has been applied to orbits of meteors appearing a quarter of a year apart. I venture to suspect, however, that if a computation of the orbits were made possible by accurate observation of the velocities, it would be found that no two orbits belonging to a stationary radiant would satisfy this criterion.

VARIABLE SPOTS ON THE MOON.

By R. S. Tozer.

When the Moon first appears in the western sky after conjunction the visible portion of it does not seem to show any difference in color or shade, but, as it proceeds in its orbit, patches of light and shade begin to develop. At full Moon the contrast between these light and dark patches is at its